ROOT AND SUCROSE YIELDS OF SUGARBEETS AS AFFECTED BY MID- TO LATE-SEASON WATER STRESS*

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Investigations of the irrigation water requirement of sugarbeets (Beta vulgaris L.) in Arizona and California have shown that water stress several weeks before harvest of fall-planted beets reduces root yields but increases sucrose concentration (2,3). Their studies showed that, since soil and plant water stress late in the season did not significantly reduce sucrose production, irrigations could be discontinued 3 to 4 weeks before harvest for maximum water economy. Mid- to late-season water deficit studies on spring-planted sugarbeets at this Center in 1977 and 1978 clearly showed that sucrose yield was reduced very little in this area, if at all, if irrigations were discontinued after the soil profile was filled with water about 1 August or 10 to 12 weeks before harvest, on soil having a useable soil water reservoir of at least 200 mm (1). However, if no rainfall occurs, a light irrigation about 1 month after water cutoff may be advantageous. The major difference between these two areas (Arizona-California and Idaho) is that in Arizona and California, potential evapotranspiration rates are higher and increasing when fall-planted beets are harvested; whereas in Idaho, potential rates are lower and decreasing when spring-planted beets are harvested. Allowing mid- to late-season water stress to develop in the Idaho area reduces irrigation water requirements by about 30% during August, September, and October when irrigation water and hydro-electric

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power for pumping are in shortest supply. Other recent investigations also show the drought tolerance of sugarbeets throughout the growing season (8, 11).

The 1977 and 1978 controlled experiments were conducted with small plots using short irrigation water runs. The objective of this study was to evaluate mid- to late-season water deficit effects on sugarbeets using the soil and irrigation water management conditions normally encountered by farm managers, thus confirming the findings of the previous 2 years.

MATERIALS AND METHODS

Two field experiments were conducted in 1979 on Portneuf silt loam soil (Durixerollic Calciorthids; coarse-silty, mixed, mesic) near Twin Falls, Idaho. The soil has a weakly cemented hardpan at the 50- to 60-cm depth that affects water movement very little when saturated but may restrict root penetration. The areas used were cropped to corn the previous year and were deficient in nitrogen (N) (5)* but had adequate phosphorus (P) (10) for sugarbeets. The plots were fertilized with N fertilizer for an expected maximum yield of 56 metric tons of beet roots per hectare.

Each field was about 2.5 hectares. A uniform application of 112 kg N/ha as ammonium nitrate was broadcast and incorporated with the upper 10 cm of soil during preparation of the seed bed.

Sugarbeets (Cultivar, Amalgamated AH-10) were planted on 6 April and 9 April in Fields 1 and 2, respectively. Rows were 56 cm apart and beets were thinned to 23 to 30-cm spacing in late May.

Six replications of three irrigation treatments (M_1, M_2, and M_3) were used. Each irrigation treatment was 14 rows wide (7.8 m) extending the length of the field (111 m). The irrigation times and amounts are summarized in Figure 1 for the following treatments:

M_1 —Farm level irrigation. Common irrigation water practice for the area and considered to be a level adequate for maximum

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*N required (kg/ha) = 4 x expected yield (metric tons/ha) minus soil test NO_3-N (kg/ha, 0-90 cm or to hard layer).

Treatment	IRRIGATIONS AND RAINFALL‡					
	to 30 June	July	Aug.	Sept.	Oct.	Total
	mm					
Rainfall			13 2			15†
Field 1						
M_1	316	61 61 61	61 79	67 85	67	858
M_2	316	61 61 61	108§	85	67	759
M_3	316	61 61 61	108§		67	674
Field 2						
M_1	197	61 61	61 79	67 85	67	678
M_2	197	61 61	108§	85	67	579
M_3	197	61 61	108§		67	494

‡ Arrows above the quantity of water refers to application date.
† After 1 August
§ Irrigated using every furrow to fill profile.

Figure 1. Irrigation water applied and rainfall.

sucrose production (4). Farm manager for Fields 1 and 2 determined irrigation water needs for the M_1 treatment until 1 August.

M_2—A light irrigation was applied on 1 September after the soil profile was filled with water on 1 August. Irrigations were the same as M_1 before 1 August.

M_3—No irrigation was applied after the soil profile was filled with water on 1 August. Irrigations were the same as M_1 before 1 August.

A light irrigation was applied to all treatments about 10 days (6 October) before harvest. Alternate furrow irrigation (every other furrow and alternating furrows at each irrigation) was used throughout the season except for the fall irrigation on 1 August, when all furrows were wetted.

The net amount of water applied was estimated using intake rates determined from previous measurements on this soil type. The following equations were used to estimate the amount applied by furrow irrigation:

$$I = 5.54t^{\frac{1}{2}} + 4.98t \qquad [1]$$

$$I = 7.21t^{\frac{1}{2}} + 6.93t \qquad [2]$$

where I is the depth of water in millimeters and t is the irrigation duration in hours. Equation [1] represents alternate furrow irrigations (112-cm intervals) and Equation [2] represents irrigations using every furrow (56-cm intervals).

The soil water content in the 0- to 30-cm depth was determined gravimetrically from 30 July to 3 October. One access tube located within the row near the center of each treatment on 4 replications and a calibrated neutron probe were used to measure soil water in the 30- to 150-cm depth from 30 July to 3 October. The bottom of the access tubes was either resting on or close to the basalt layer.

In mid-October, the fields were divided lengthwise into 3 (37 m each) sections (upper, center, and lower part of the field) and the beet roots were mechanically harvested (16 October) taking 4 center rows from each treatment and keeping the yield parameters separate for each section. Sucrose concentration and extractability were determined on two samples (14-18 roots each) of randomly selected roots from each section of each treatment by the Amalgamated Sugar Company using the Sach-le Docte cold digestion procedure as outlined by McGinnis (7). Water percentage in the beet roots was determined by the weight loss by drying at 65°C of brei samples collected at the time of sucrose analysis.

RESULTS AND DISCUSSION

Root yields were nearly uniform in the upper and center sections of the field on three irrigation levels for each of the two experimental fields (Table 1A). Root yields were larger (about 10%) on the lower section of the M_1 and M_2 irrigation levels on both fields. However, on the M_3 irrigation level, yields were nearly the same in the upper, center, and lower sections. As a result, the average root yields on the M_3 irrigation treatment for each of the fields was 5% less than on the M_1 irrigation treatment. No consistent differences were noted in root yields between the M_1 and M_2 irrigation level for each section or treatment within each experimental field.

Sucrose concentration was rather uniform throughout each field section and irrigation level for each of the two fields (Table 1B). There were no significant irrigation treatment effects on sucrose concentration on either of the two experimental fields. Mid- to late-season plant water stress in previous experiments (1) showed an increase in sucrose concentration during the season and at harvest which was caused by dehydration of the beet roots. However, in this experiment, the preharvest irrigation gave the

Table 1. Effect of mid- to late-season moisture stress on root yield, sucrose concentration, and percentage moisture in the roots. See text and Figure 1 for treatment identification.

Treatment	Treatment Means					
	Field 1			Field 2		
	M_1	M_2	M_3	M_1	M_2	M3
A						
	Root yield, metric tons/ha					
Upper	53.0	51.5	53.1	63.1	63.0	61.3
Center	53.7	51.9	52.4	64.6	61.9	61.7
Lower	59.3	57.6	53.3	70.4	70.1	63.5
Average	55.3	53.6	52.9	66.0	65.0	62.2
5% LSD interaction = 3.00, Treatment = 2.24						
B						
	% Sucrose					
Upper	17.01	17.31	17.29	17.76	17.75	17.71
Center	17.47	17.32	17.25	17.98	17.78	17.76
Lower	16.93	17.19	17.22	17.45	17.79	17.64
Average	17.14	17.27	17.25	17.73	17.78	17.70
5% LSD interaction = 0.25, Treatment = 0.14						
C						
	% Root Moisture					
Upper	79.2	78.6	78.6	78.2	77.9	78.3
Center	78.6	78.6	78.8	78.0	78.2	78.1
Lower	79.0	79.1	78.6	78.5	78.2	78.6
Average	78.9	78.8	78.7	78.2	78.1	78.3
5% LSD interaction = 0.53, Treatment = 0.31						

beets enough water and time (10 days) for rehydration of the roots (Table 1C) which masked any differences in sucrose concentration due to dehydration that may have occurred earlier.

Sucrose yield was mainly controlled by the treatments that affected the level of root production (Table 2A). Significant decreases in sucrose yield of 8% occurred on the lower section of the M_3 irrigation level on each of the two fields as compared with lower end of the M_1 level. However, the overall irrigation treatment effect was insignificant for Field 1 and a significant 6% reduction for Field 2 when the M_3 was compared with the M_1 irrigation level. Little consistent variation in sucrose extractability was associated with treatment (Table 2B). However, beet roots on the lower section of the M_3 irrigation level tended to have a lower percentage extractability than other parts of the field and Field 2 had a higher extractability than Field 1. As a consequence, there was no difference in extractable sucrose between the M_1 and M_2 irrigation level due to field position or treatment (Table 2C). Extractable sucrose was 9% lower on the lower section of the M_3 level when compared with the M_1 irrigation treatment on the lower section of both fields. There were no treatment effects on extractable sucrose on Field 1 but on Field 2 a significant 6% decrease occurred on the M_3 as compared with the M_1 irrigation level.

Table 2. Effect of mid- to late-season moisture stress on sucrose yield, percentage extractability of sucrose, and extractable sucrose yield. See text and Figure 1 for treatment identification.

	Treatment Means					
	Field 1			Field 2		
	M_1	M_2	M_3	M_1	M_2	M_3
			A			
	Sucrose yield, kg/ha					
Upper	9,020	8,920	9,200	11,230	11,180	10,860
Center	9,390	8,970	9,110	11,620	11,010	10,970
Lower	9,990	9,850	9,180	12,290	12,480	11,200
Average	9,470	9,250	9,160	11,710	11,560	11,010
5% LSD interaction = 594, Treatment = 403						
			B			
	% Sucrose Extractability					
Upper	86.7	86.9	86.7	87.4	87.6	87.7
Center	86.3	85.5	85.3	87.4	87.8	87.3
Lower	85.0	85.6	84.8	87.0	87.2	86.3
Average	86.0	86.0	85.6	87.3	87.5	87.1
5% LSD interaction = 0.58, Treatment = 0.45						
			C			
	Extractable sucrose yield, kg/ha					
Upper	7,820	7,750	7,970	9,830	9,790	9,530
Center	8,110	7,670	7,790	10,160	9,660	9,580
Lower	8,490	8,430	7,790	10,690	10,880	9,670
Average	8,140	7,950	7,850	10,230	10,110	9,590
5% LSD interaction = 531, Treatment = 354						

The decrease in root, total sucrose, and extractable sucrose yields with the M_3 irrigation treatment on the lower section of both fields appeared to be caused by land leveling of these fields during past years. For example, on Field 1 the cut area of the lower part of the field extended through the first three replications. The only replications where significant decreases in extractable sucrose occurred were on the cut area (Figure 2). In these areas, the topsoil had been removed exposing the subsurface soil with its lower infiltration rate and water holding capacity. Also, in the cut areas, the distance from the surface to the basalt was reduced by 30 to 60 cm. The soil profile in these leveled areas was not able to absorb or hold enough water after the 1 August water cutoff to maintain sufficient leaf turgidity, CO_2 absorption and photosynthate production for maximum root and sucrose yield. In these cut areas and in other shallow soils with a water holding capacity less than 200 mm, a short irrigation about 1 month after water cutoff would be essential if not enough rain fell during this period to maintain maximum sucrose production.

Generally, the root zone for sugarbeets on this soil has been considered as the soil above the hard layer (top 60 cm). In these experiments and previous related studies (1), it was quite obvious

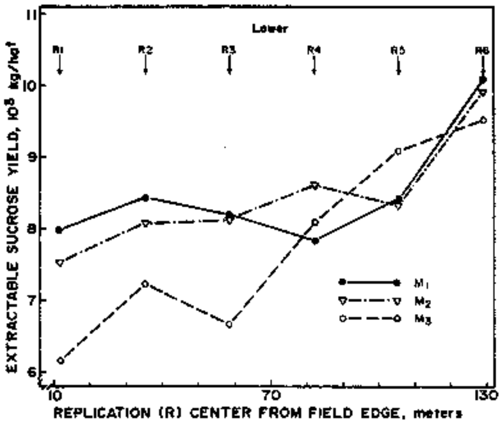

Figure 2. Extractable sucrose yield as affected by field position and irrigation water treatment on Field 1. See text and Figure 1 for treatment identification. †Extractable sucrose yield is graph units x 10^3.

that the water used for evapotranspiration (ET) came from all soil layers (Figure 3). When the surface soil contained enough soil water for adequate plant growth such as the M_1 irrigation treatment, as much as 80% of the water used for ET came from above the hard layer (Figure 4). However, as the surface soil dried and approached the wilting range, as much as 80% of the water used for ET came from the hard layer and below (60 to 150 cm). If, during the water stress period an irrigation was applied such as the one on 1 September or if it rained, there was a temporary increase in the surface water used followed again by the increased use of the deeper water for ET. For this crop to use the water from within the considered root zone (top 60 cm), the deeper water would have to move by upward flow through the hard layer to the root zone. From water and hydraulic conductivity measurements (9) on this soil, we determined that adequate water could move through the hard layer to supply the ET requirements of the plants when this layer was wet. However, as the hard layer and below dried, hydraulic conductivity decreased to a point where only a fraction

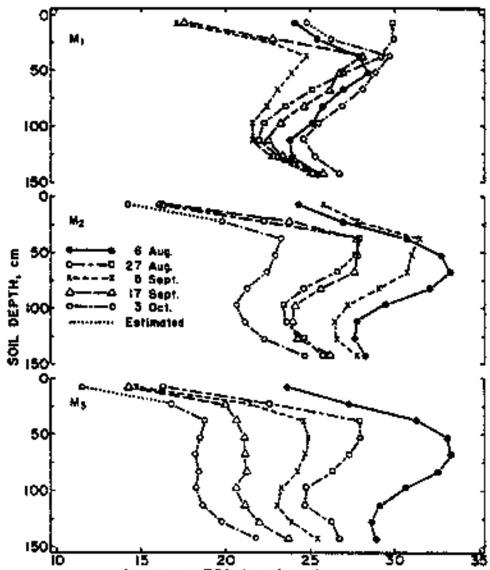

Figure 3. Soil water on five dates illustrating the pattern of water use on the M_1, M_2 and M_3 irrigation treatments during August, September, and October using average values from Fields 1 and 2. See text and Figure 1 for treatment identification.

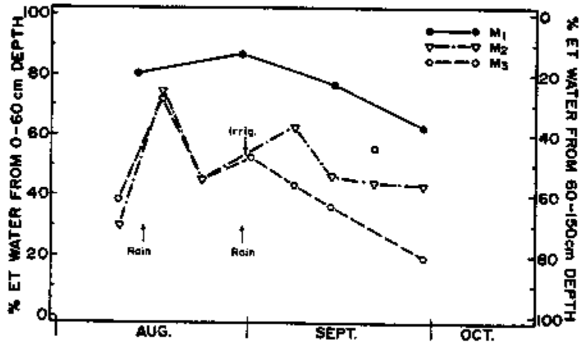

Figure 4. Estimate of the percentage of water used for ET that was taken from above the hard layer (0 - 60 cm), and within and below the hard layer (60 - 150 cm) using average values from Fields 1 and 2. See text and Figure 1 for treatment identification.

of the necessary water could move through the hard layer to supply the ET water used by the plant. A mechanism that may have accounted for the rest of the extracted water was that the roots were able to penetrate the hard layer through small cracks or in holes made by roots from previous crops having a stronger rooting system such as alfalfa. This is supported by observations made by others *where sugarbeet roots were found below the hard layer on this soil type (6). Regardless of the mechanism, the water reservoir within and below the hard layer did supply enough water to the sugarbeet plants to keep the growth process active and yields either equal or only slightly reduced when the top soil was near the wilting point for plant growth.

When adequate soil water was present, the ET, estimated from water depletion of the profile using average neutron probe measurements for the two fields, followed a rather consistent pattern and was similar to those found in 1977 and 1978 (1) as compared with the potential or reference ET (alfalfa, Medicago sativa L.) determined by a modified method of Wright and Jensen (12), (Figure 5). Evapotranspiration generally decreased after water cutoff as the soil water was depleted and as the potential ET decreased because of lower solar radiation and air temperatures. Evapotranspiration increased after significant effective rainfall on all water cutoff

*R. A. Kohl and J. W. Cary, personal communication.

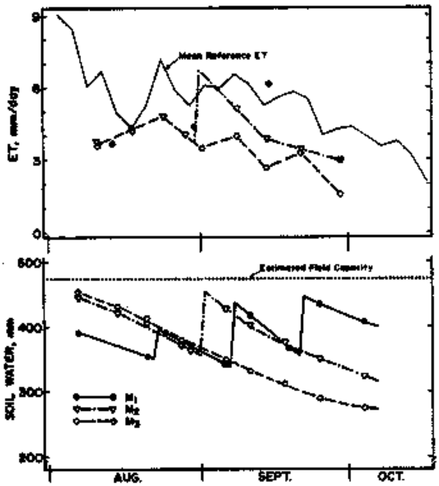

Figure 5. Measured soil water content and ET using averages from Fields 1 and 2, mean reference ET, and estimated field capacity determined at 0.33 bar (9). Mean (3-day) reference ET (alfalfa) determined by a modified method of Wright and Jensen (12). See text and Figure 1 for treatment identification.

treatments and on the M_2 irrigation level after the 1 September irrigation because of the increased surface-available water. Evapotranspiration values ranged from 5.1 mm/day in early September after the 1 September irrigation to 3 mm/day in early October on the M_2 irrigation level and from 4.8 mm/day after the rain in mid-August to 1.6 mm/day in early October on the M_3 treatment. Compared with the M_1 treatment, the water stress treatments reduced total ET by 13 and 52 mm for the M_2 and M_3 irrigations, respectively, for the period August to October. These reductions in ET were much less than those found in 1977 and 1978 using similar irrigation treatments.

The available water in the profile on the water cutoff treatments steadily decreased during August and September without either irrigation or significant rainfall (Figure 5). The total available water in these silt loam soils between the estimated field capacity (0.33 bar) and the maximum extraction (about 10 bar) is about 260 mm (1). The total water used between the estimated field capacity and maximum extraction in this experiment was 150 mm of water on the M_2 level and 198 mm on the M_3 irrigation level. This demonstrated that 200 mm of available water was present in this soil and that an additional 60 mm of water would probably have become available in the non-cut areas if water cutoff had been earlier. However, in the cut areas, it was quite obvious from the moisture stress placed on the plants and the resulting root and sucrose yield decreases, that far less water was available to those plants than to plants in the other areas where the access tubes were located. The irrigation water use on the M_3 level, as compared with the M_1 irrigation level, was reduced by 22 and 27% for Fields 1 and 2, respectively.

Table 3. Water balance during the period of irrigation water cutoff in 1979 using average values from Fields 1 and 2. See text and Figure 1 for treatment identification.

Source of water gain or use	6 August to 3 October		
	M_1	M_2	M_3
	mm		
Change in soil water (ΔSW)	+15	−122	−179
Evapotranspiration (ET)	246	233	194
Deep percolation, assumed	0	0	0
Water balance (ET + ΔSW)[a]	261	111	15
Water applied and rainfall[b]	246	100	15

[a]Estimate of irrigation water applied and rainfall based on ET and ΔSW from 6 August to 3 October.

[b]Estimate of irrigation water applied based on water infiltration and rainfall using Eq. [1] from 6 August to 3 October.

The overall water balance during the period of irrigation water cutoff is given in Table 3. The water application amounts calculated from the soil water data (ET + ΔSW) are only slightly higher than the application amounts shown in Figure 1 for the period from 6 August to 3 October. This would indicate that the infiltration Eq. [1], which was determined using intake rates in 1978 (1) and previous intake measurements on this soil type, was within the necessary accuracy for estimating water application rates used in this experiment. This would also indicate that the estimated ET rate after 1 August was within the necessary accuracy for measurement of the water used in this experiment.

The results of these experiments confirmed on a field scale the findings of the previous 2 years that in these silt loam soils irrigations can be discontinued after filling the soil profile with water about 1 August with very little, if any, loss in root or sucrose yield. However, if no rainfall occurs after water cutoff or if the available soil water in the profile is less than 200 mm, a supplementary light irrigation about 1 month after water cutoff may be advantageous. In this experiment, a supplementary light irrigation was necessary only in the cut areas of the fields where less than 200 mm of soil water was available to sustain plant growth and photosynthate production during the stress period. A light irrigation before harvest may also be necessary to prevent loss of roots by breaking if conventional harvesting equipment is used.

The use of deficit water management during August, September, and October as found in 1977-78 (1) and in this experiment has the advantages of 1) lower irrigation water needs of sugarbeets; 2) lower irrigation water demand during August through October in water-short years; 3) lower irrigation labor costs; and 4) lower pumping costs, a particularly important advantage in high lift irrigation districts. If the beet roots are harvested from a dry soil without preharvest irrigation, then additional advantages would be 5) lower processing costs because of higher root quality resulting from higher sucrose concentrations; 6) lower hauling costs because the lower water content reduces both the weight and volume of the harvested roots; and 7) a depleted soil water reservoir at the end of the season, which would increase the retention of overwinter precipitation. The use of mid- to late-season deficit water management could substantially reduce sugarbeet production costs in irrigated areas and economically benefit the consumer, producer, and manufacturer.

SUMMARY

This sugarbeet (Beta vulgaris L.) experiment involving three irrigation water levels and two separate fields, was conducted to evaluate mid- to late-season water deficit on this crop using soil and irrigation water management conditions normally encountered by farm managers. These experiments demonstrated that sucrose

yield is reduced very little, if at all, in this area in Idaho if irrigations are discontinued after filling the soil profile with water about 1 August and if the soil contains at least 200 mm of available water to a soil depth of 150 cm. However, if no rainfall occurs after water cutoff or the available soil water in the profile is less than 200 mm, a supplementary light irrigation about 1 month after water cutoff may be advantageous. The use of mid- to late-season deficit water management could substantially reduce sugarbeet production costs in irrigated areas. The results of these experiments confirm on a field scale basis the findings of a more detailed plot study in 1977-78.

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